Tribology of Polymer Matrix Composites (PMCs) Fabricated by Additive Manufacturing (AM)

S. Gupta[1], R. Dunnigan[1], A. Salem[2], L. Kuentz[3], M. C. Halbig[4], and M. Singh[5]

[1]Department of Mechanical Engineering
University of North Dakota, Grand Forks, ND 58201

[2]Hawken School, Gates Mills OH 44040

[3]Lake Ridge Academy, North Ridgeville, OH 44039

[4]NASA Glenn Research Center, Cleveland, OH 44135

[5]Ohio Aerospace Institute, Cleveland, OH 44142

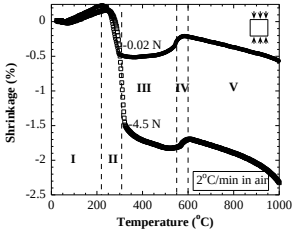
Brief Overview of Collaborative Research

Advanced Materials Processing

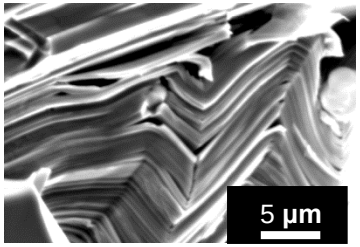
Novel Processes

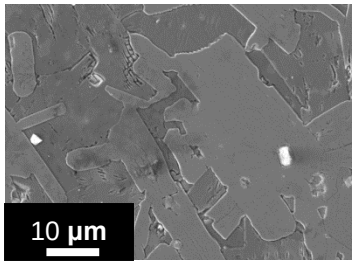


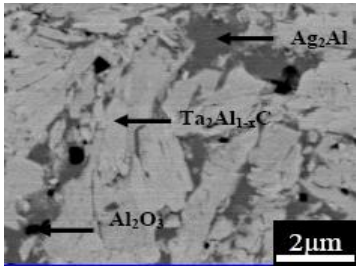

Fundamentals

Engineer Novel Microstructures



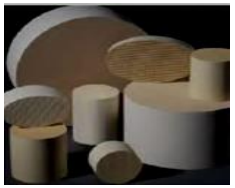




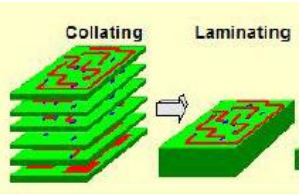
Properties and Applications

Aerospace

Automobile



Electronics



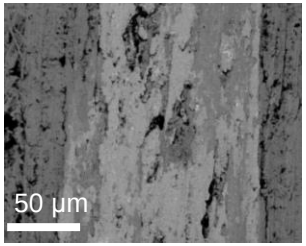
Biomaterials

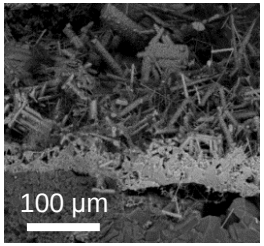
High Temperature

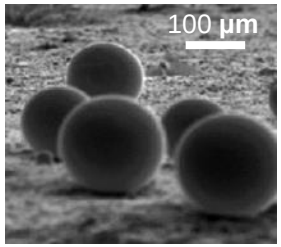
Environment

Fundamental and applied research

Study of Surfaces and Interfaces







Adaptive Coatings | Oxide Whiskers | In Globles on Zr_2InC

A nascent area for fundamental research

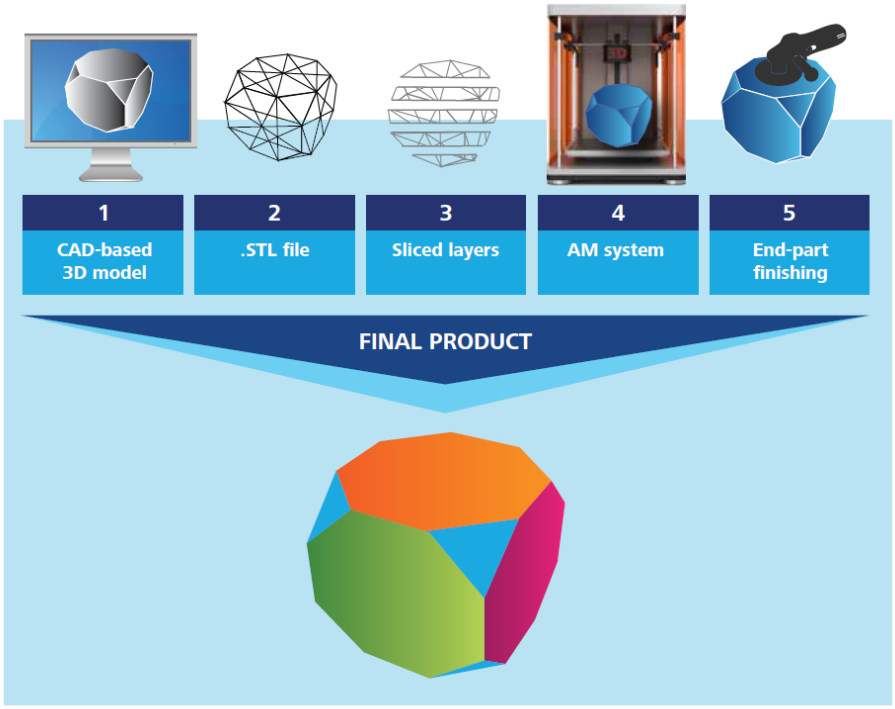
University of North Dakota


CALL FOR PAPERS
Abstracts due December 15, 2015
9TH INTERNATIONAL CONFERENCE ON HIGH TEMPERATURE CERAMIC MATRIX COMPOSITES - HTCMC 9
GLOBAL FORUM ON ADVANCED MATERIALS AND TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT - GFMAT 2016
JUNE 26 – 30, 2016

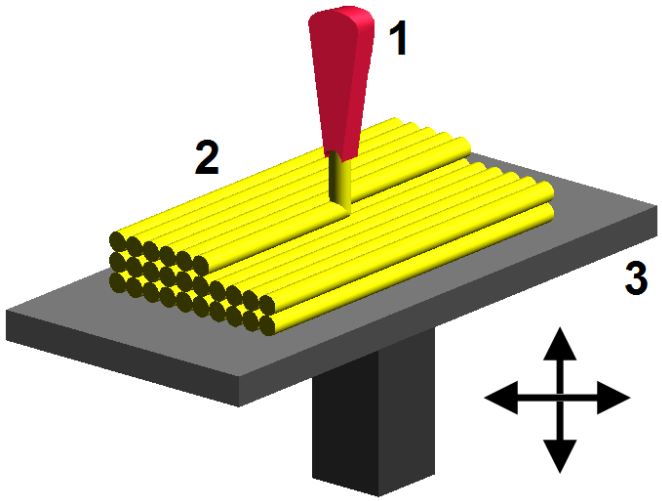
Outline

- Background and Introduction
  - Additive Manufacturing Technologies
- Objectives
- Materials and Procedures
- Results and Discussion
  - *Starting Materials*
  - *Printing Parameters*
  - *Reinforcements*
  - *Tribological Behavior*
- Summary and Conclusions
- Future Work

Additive Manufacturing/3-D Printing (Schematic)



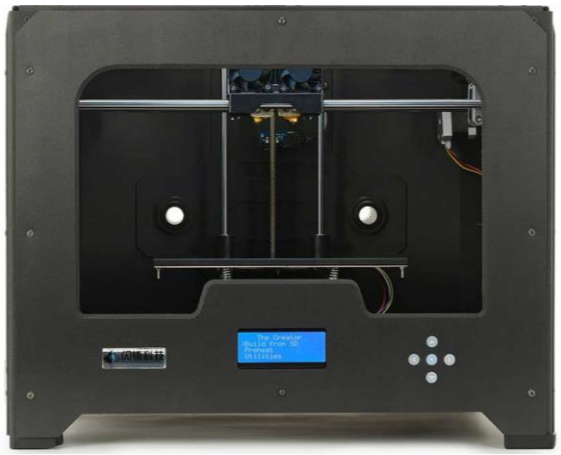
Graphic: Deloitte University Press | DUPress.com



Successive layers of material are formed under computer control to create an object

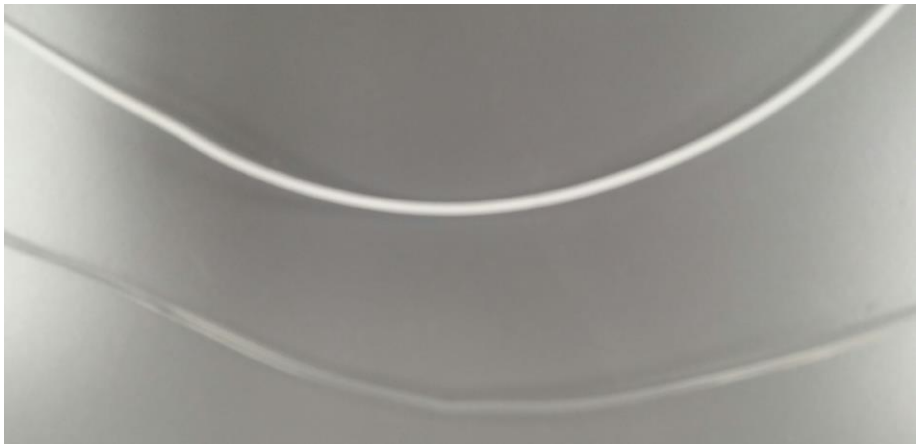
3D Printers used for Research

- Afinia H480 3D Printer
- Flashforge Creator Pro 3D Printer
- Form 1+ 3D Printer



Filabot Extruder

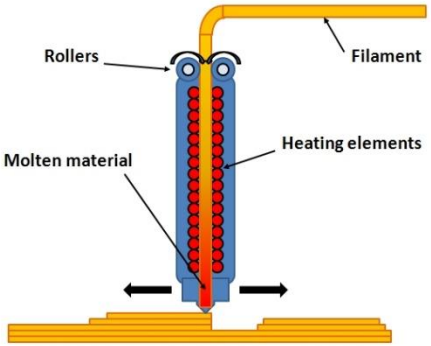
- Uses pellets/powders to create filament for FDM 3D printing
- Materials extruded include PLA, MDPE, and HIP



PLA	175	220	250
MDPE	105	115	N/A
HIP	200	230	266

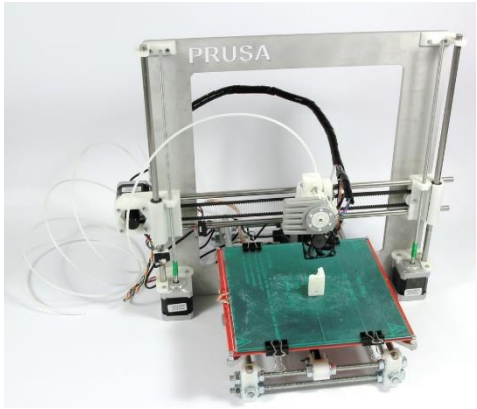
Fused Deposition Modeling (FDM) Based Additive Manufacturing/3-D Printing

Industrial scale FDM systems (Stratasys)

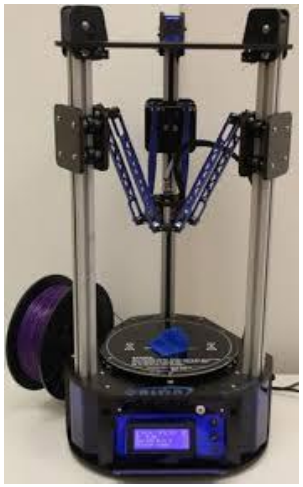


Process Schematic

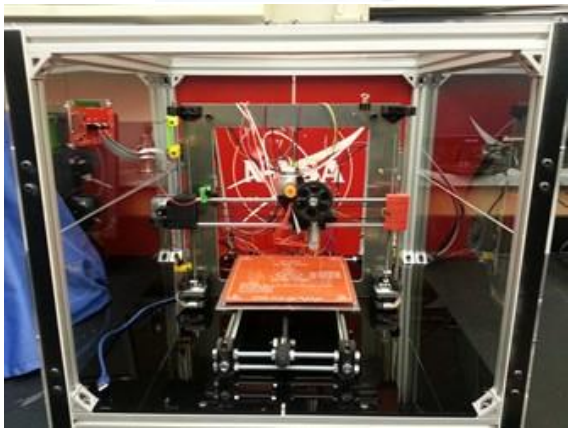
RepRap



MakerBot Replicator 2X



Orion Delta 3D Printer



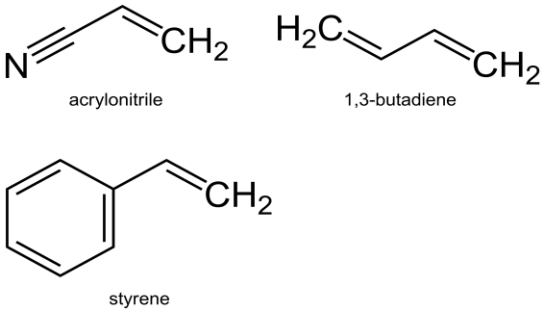
"RepRap is humanity's first general-purpose self-replicating manufacturing machine". www.reprap.org

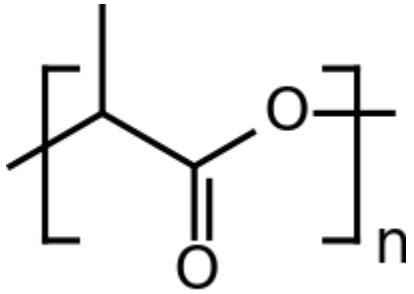
Objective

To Compare the tribological properties of composite ABS and PLA materials to the pure ABS and PLA:

- Microstructure-Properties-Performance
- Tribological Performance
- Wear Rates
- Friction Coefficients
- Effect of Print Layer Heights

ABS and PLA





ABS (Acrylonitrile Butadiene Styrene)

Polylactic Acid (PLA)

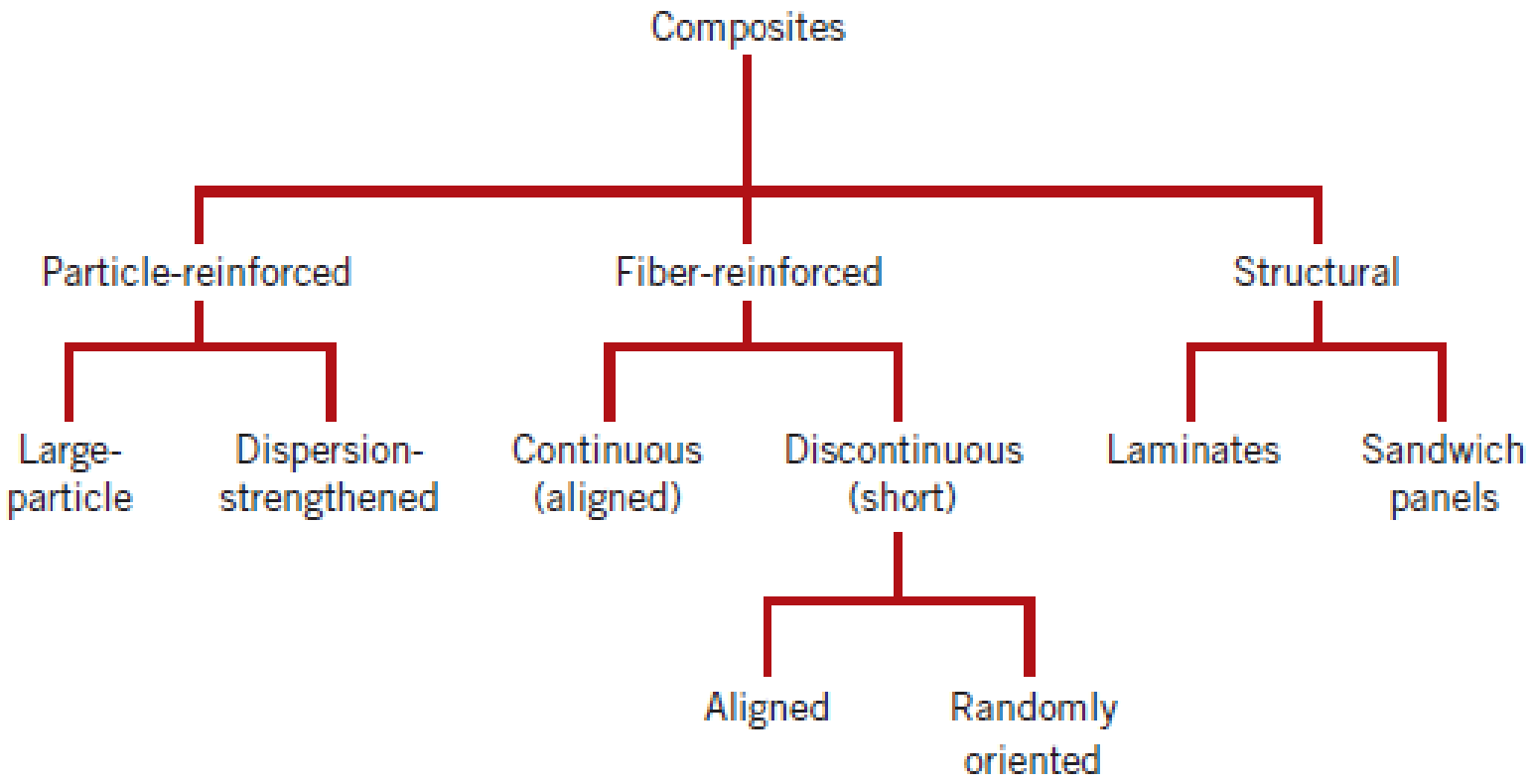
- PLA Benefits:
  - ➢ Environmentally friendly
  - ➢ Does not release toxic fumes/safe for people

- ABS Benefits
  - ➢ Have impact resistance and toughness
  - ➢ Resistant to aqueous acids, alkalis etc.

Following Materials were Studied

- **Color Fab, bronze fill metal, PLA**
- **GMASS, Tungsten, ABS**
- **Proto Pasta, Magnetic iron, PLA**
- **3DXTech, premium red, ABS**
- **3DXNano ESD (CNT) black, ABS**
- **Color Fab, copper fill metal, PLA**
- **GMASS, Bismuth, ABS**
- **Proto Pasta, Stainless Steel, PLA**
- **3DXTech, black, ABS**
- **Carbon Fiber 5 wt%, ABS**

Types of Composites



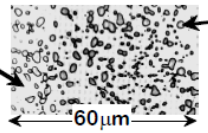
Background

COMPOSITE SURVEY: Particle

Particle-reinforced | Fiber-reinforced | Structural

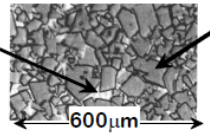
- Examples:

-Spheroidite steel — matrix: ferrite (α) (ductile); particles: cementite (Fe_3C) (brittle)



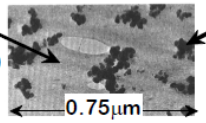
Adapted from Fig. 10.10, *Callister 6e.* (Fig. 10.10 is

-WC/Co cemented carbide — matrix: cobalt (ductile) V_m: 10-15vol%!; particles: WC (brittle, hard)

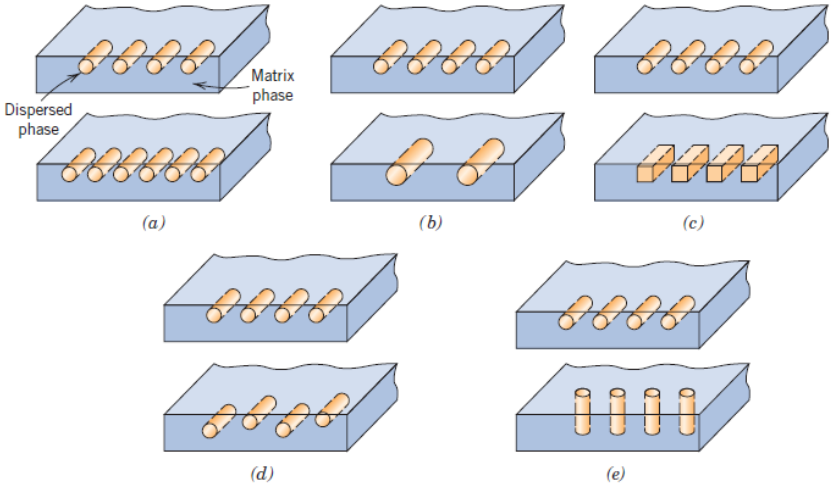


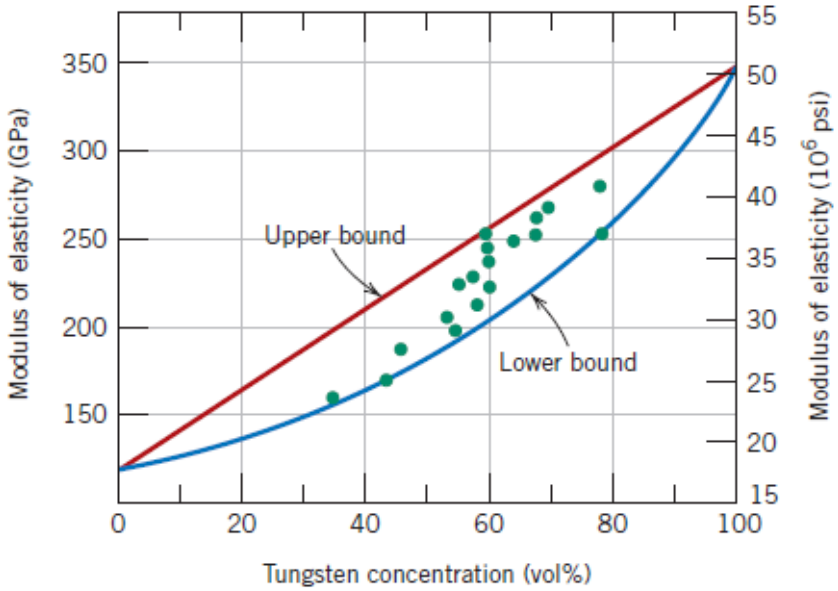
Adapted from Fig. 16.4, *Callister 6e.* (Fig. 16.4 is

-Automobile tires — matrix: rubber (compliant); particles: C (stiffer)



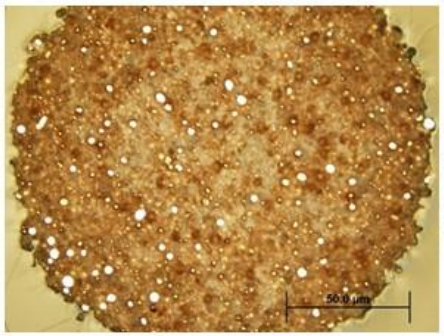
Adapted from Fig. 16.5, *Callister 6e.* (Fig. 16.5 is



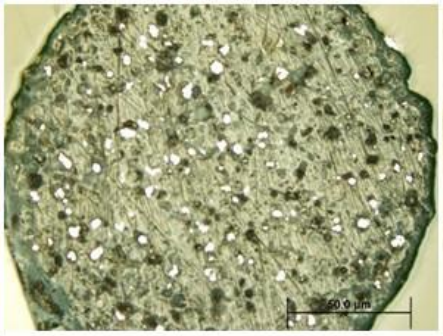


$$E_c(u) = E_m V_m + E_p V_p$$

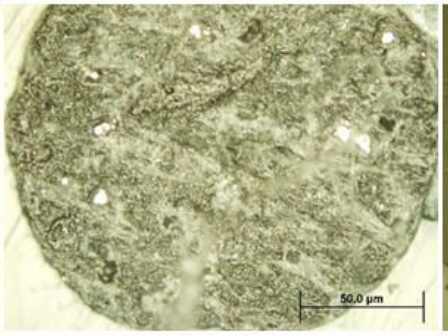
3-D Printing of Multi-Functional Materials



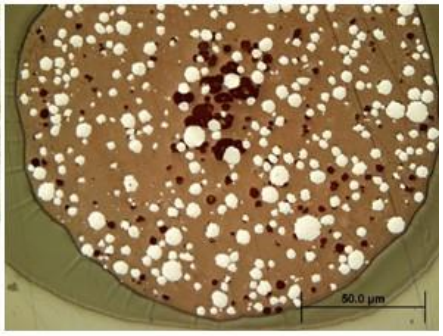
Color Fab, copper fill metal, PLA



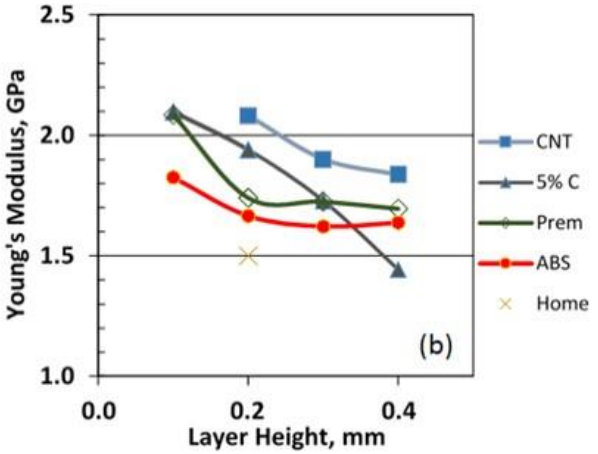
Proto Pasta, Magnetic iron, PLA

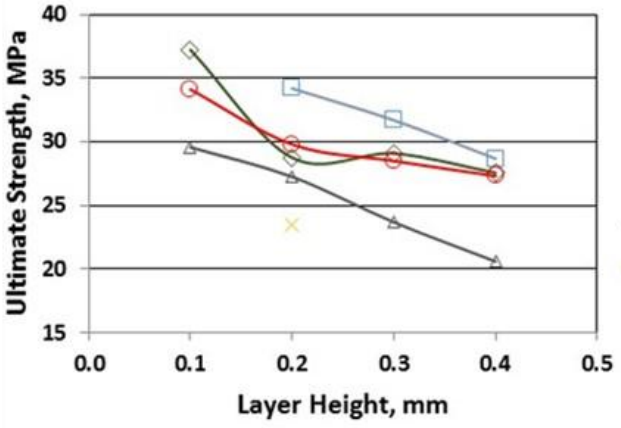


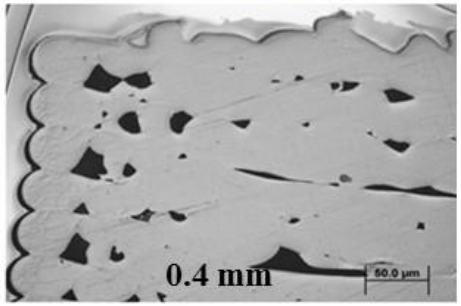
GMASS, Tungsten, ABS

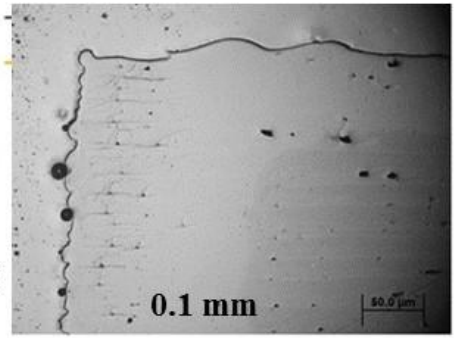


GMASS, Bismuth, ABS







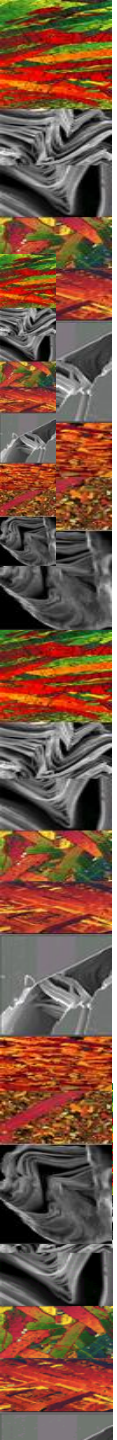


Highest strength and modulus in CNT reinforced coupons
Pure ABS Coupons – less porosity for lower print heights

Measurement of Friction Coefficient (μ) and Wear Rate (WR)

- Tab on disc method
- Sample shape : 4 mm x 4 mm x (1.5-1.7) mm (MAX phases)
- Dynamic partner : Alumina
- Load: 5 N
- Rotation speed: 31 cm/s
- Temperature: RT Tested in ambient air

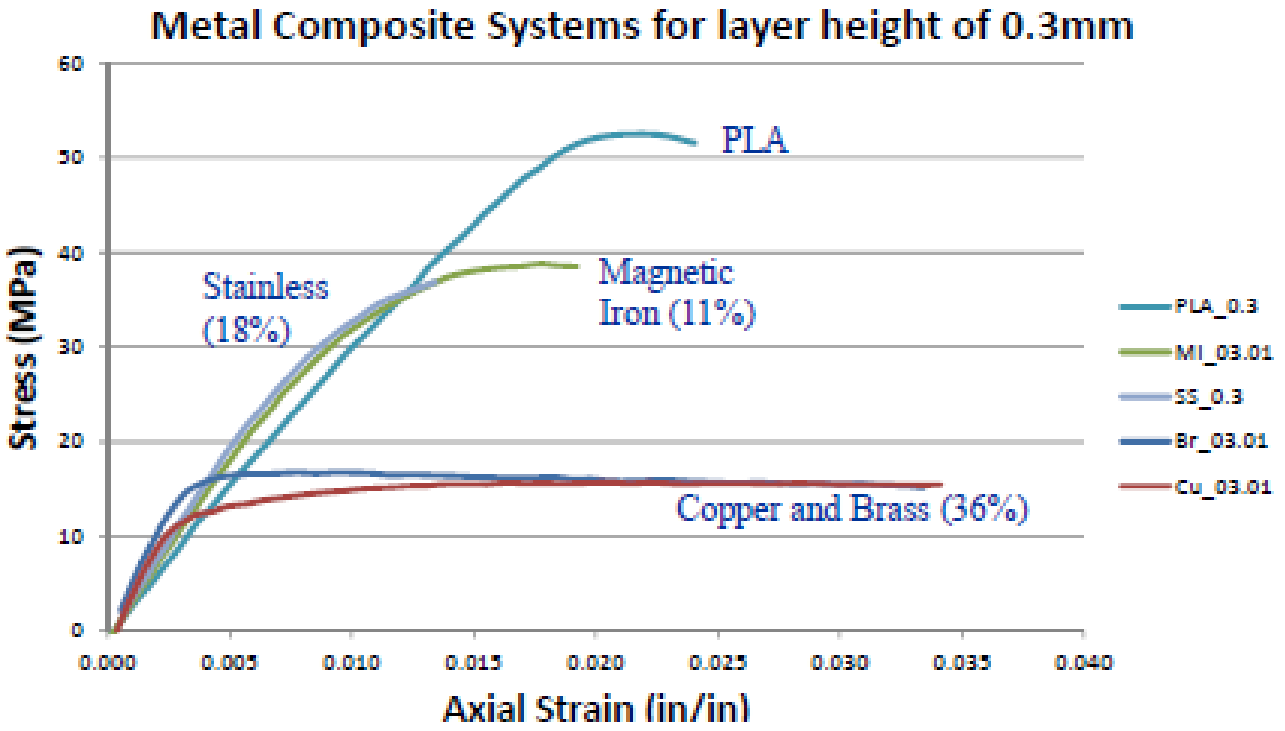
CSM TRIBOMETER



PLA and PLA Composites

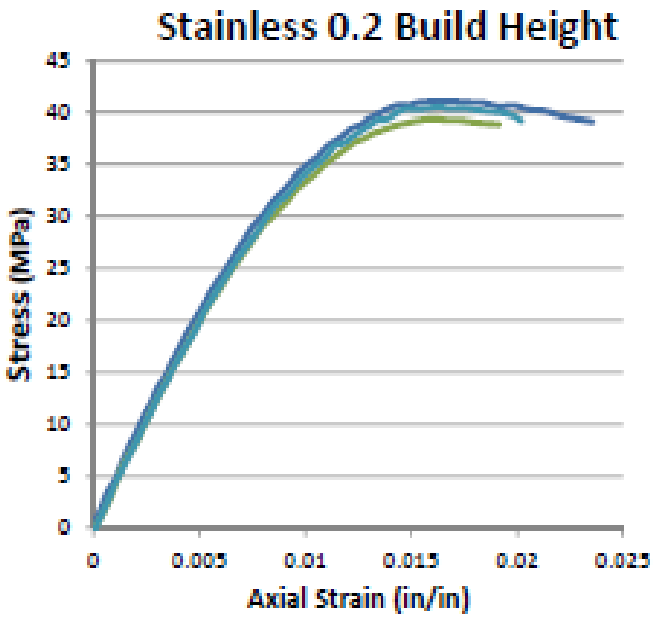
Mechanical Behavior of PLA and PLA Composites

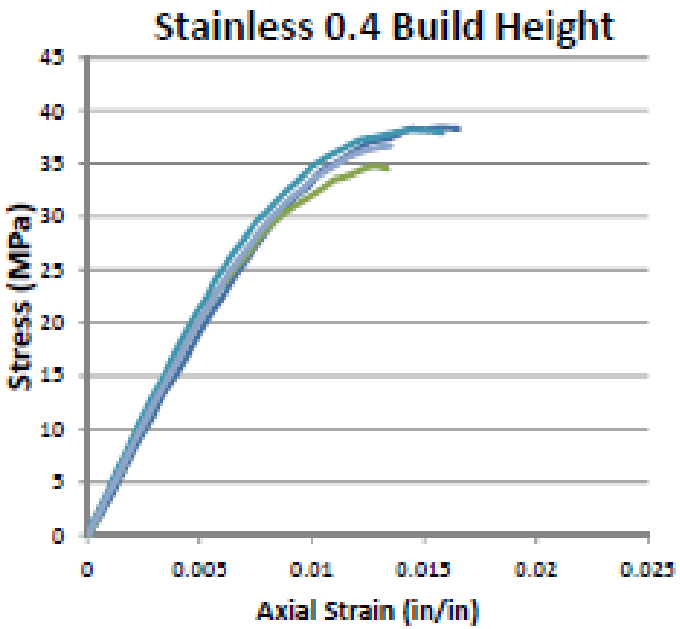
PLA shows the greatest strength:



Mechanical Behavior of PLA and PLA Composites

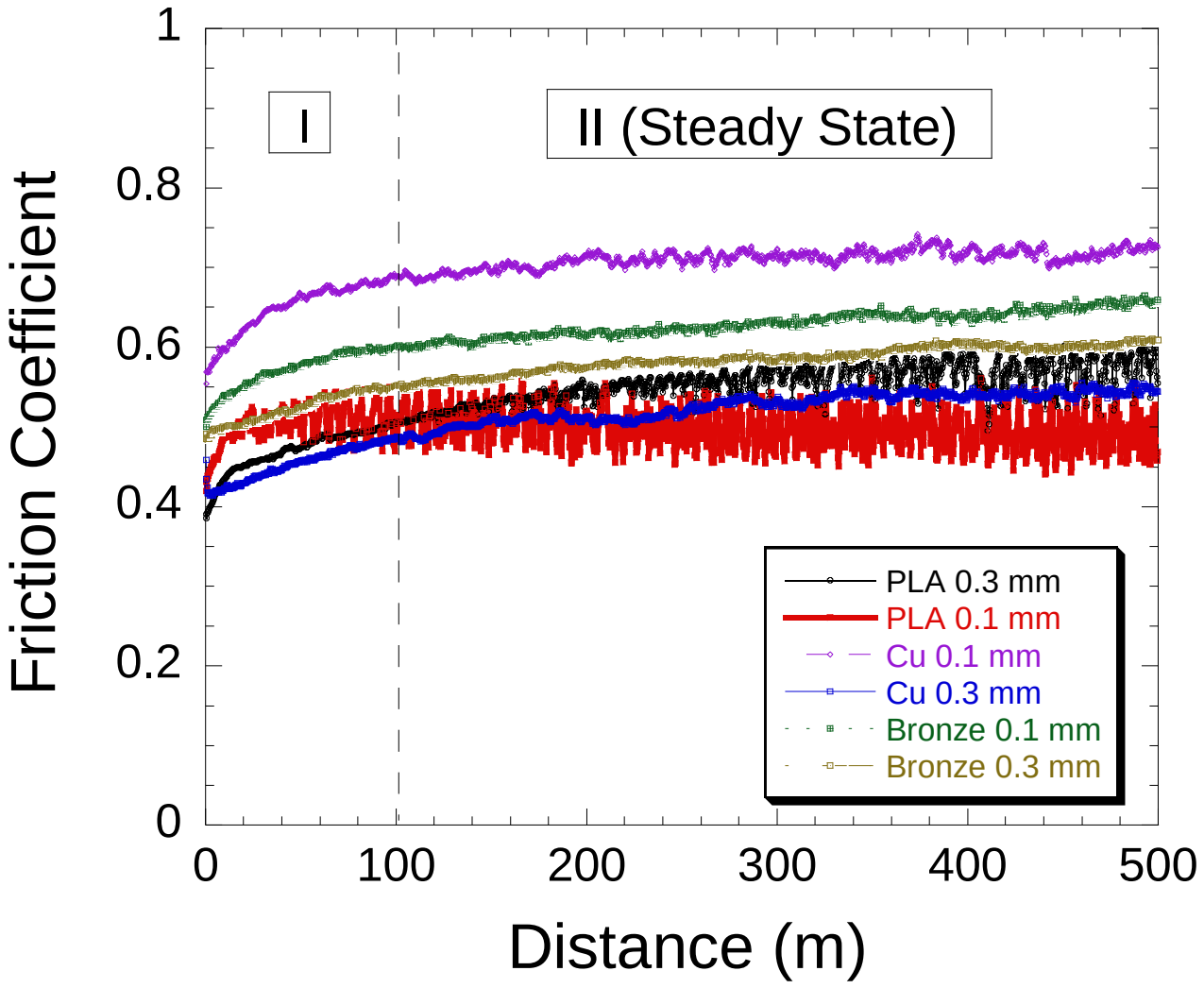
- Metal filled PLA show an effect of layer height:



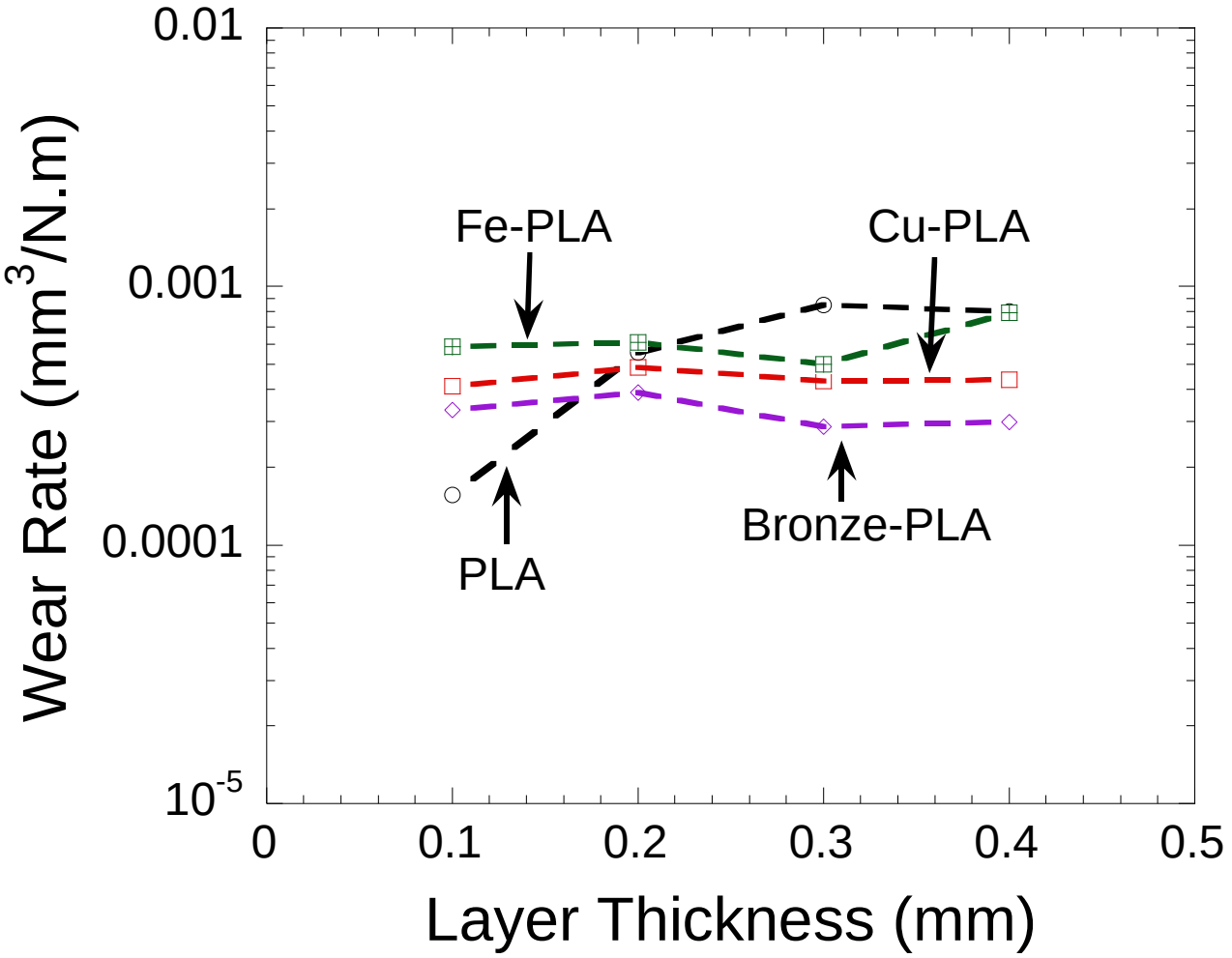


- Lower strength and strain to failure.

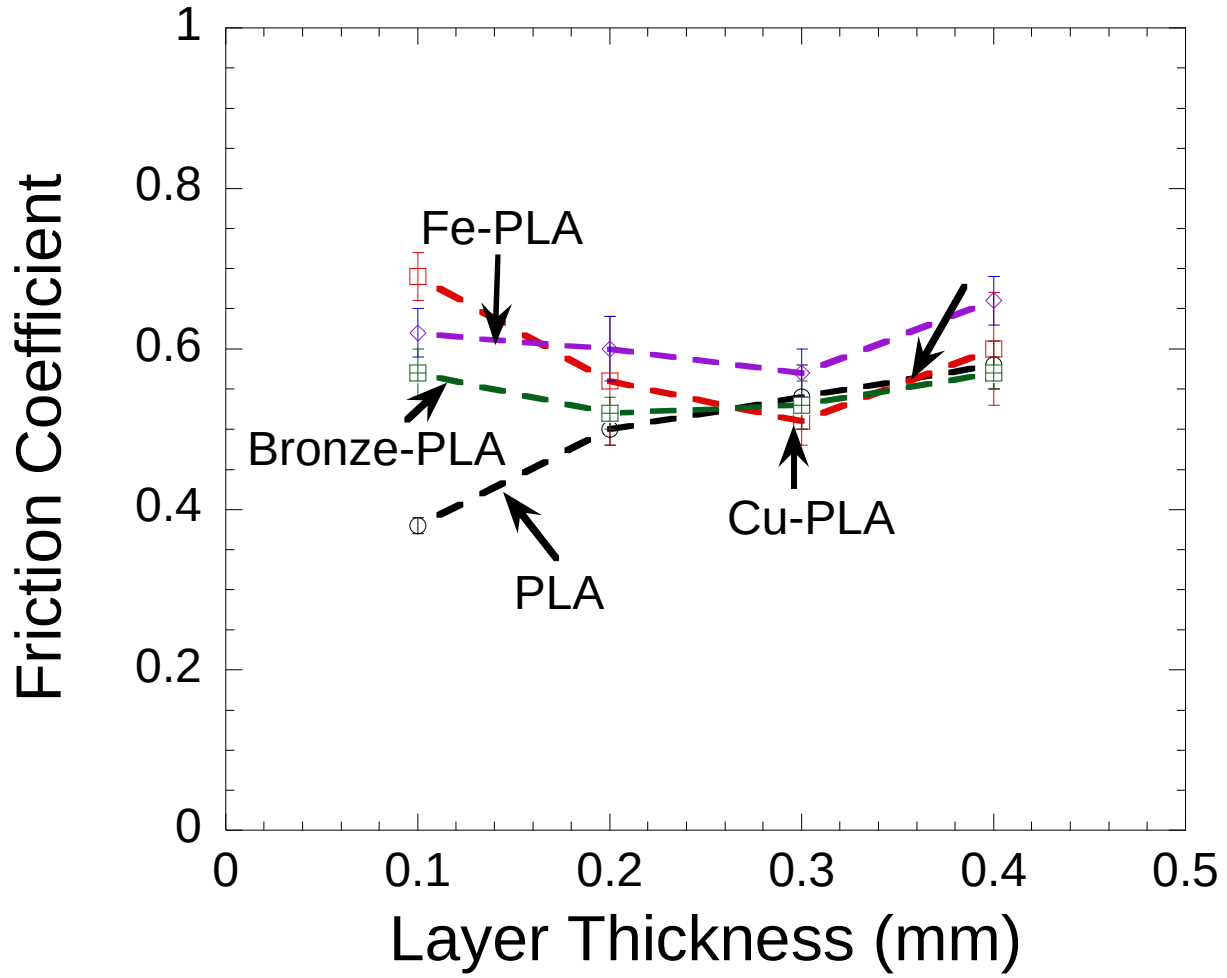
Friction Coefficient of PLA and PLA Composite Materials

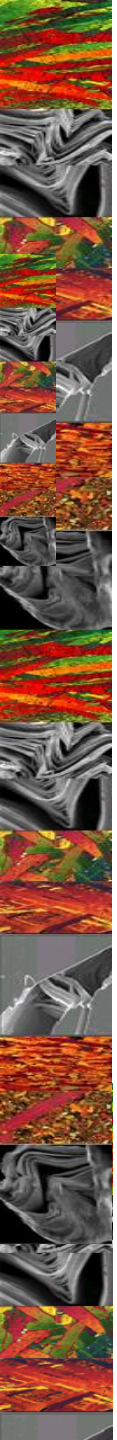


Variation of Wear Rate vs Print Layer Height in PLA and PLA Composites



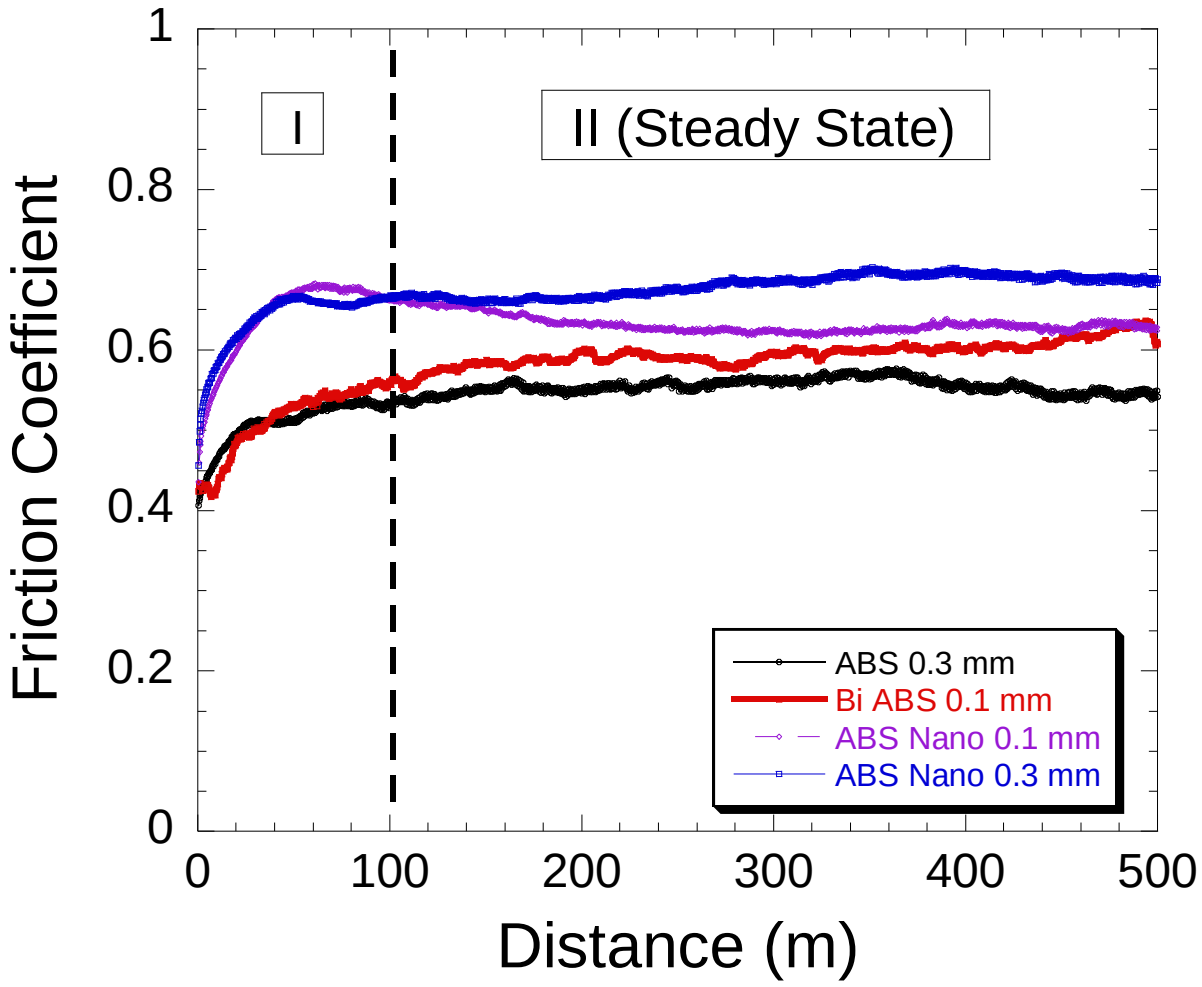
Variation of Friction Coefficient vs Print Layer Height in PLA and PLA Composites



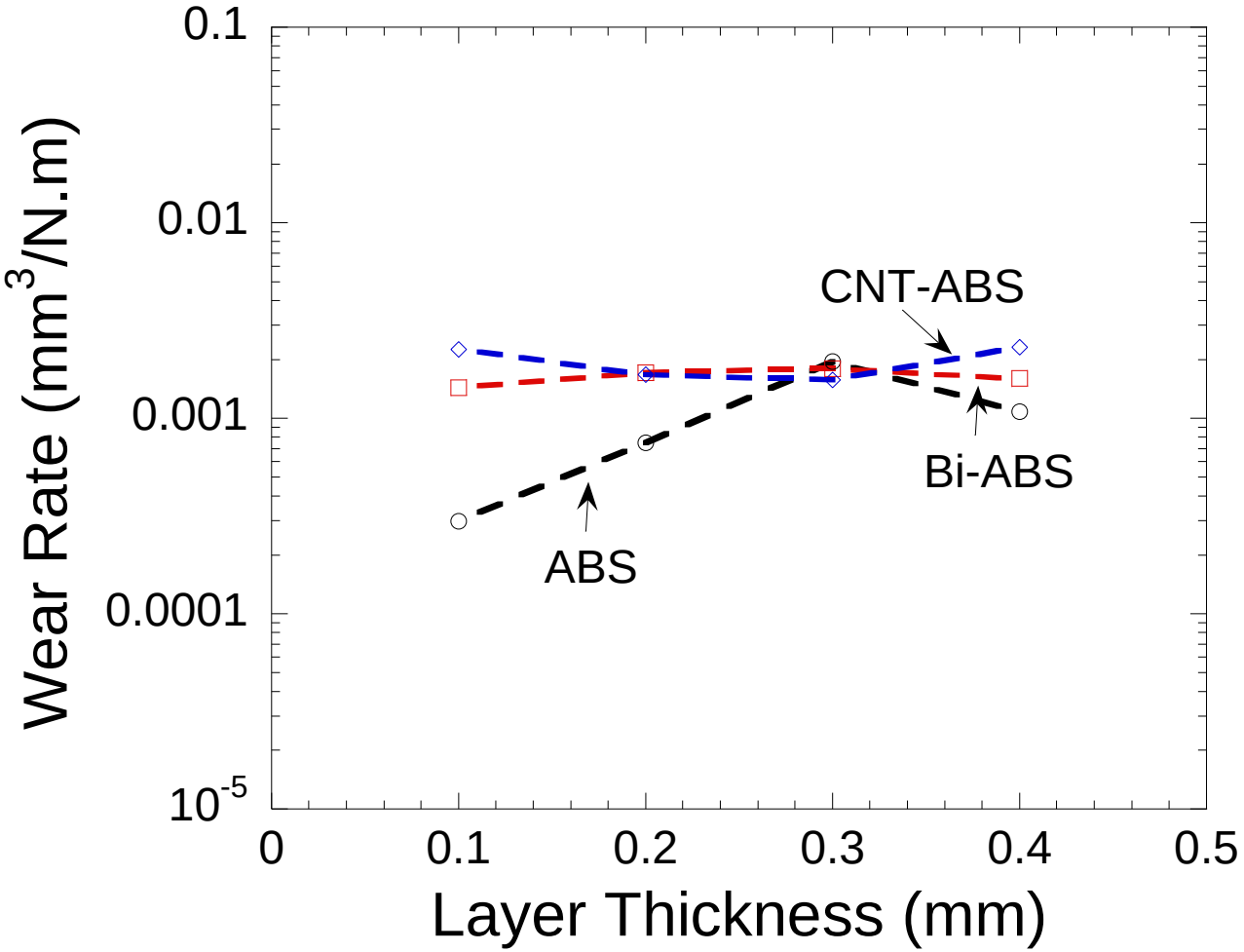


ABS and ABS Composites

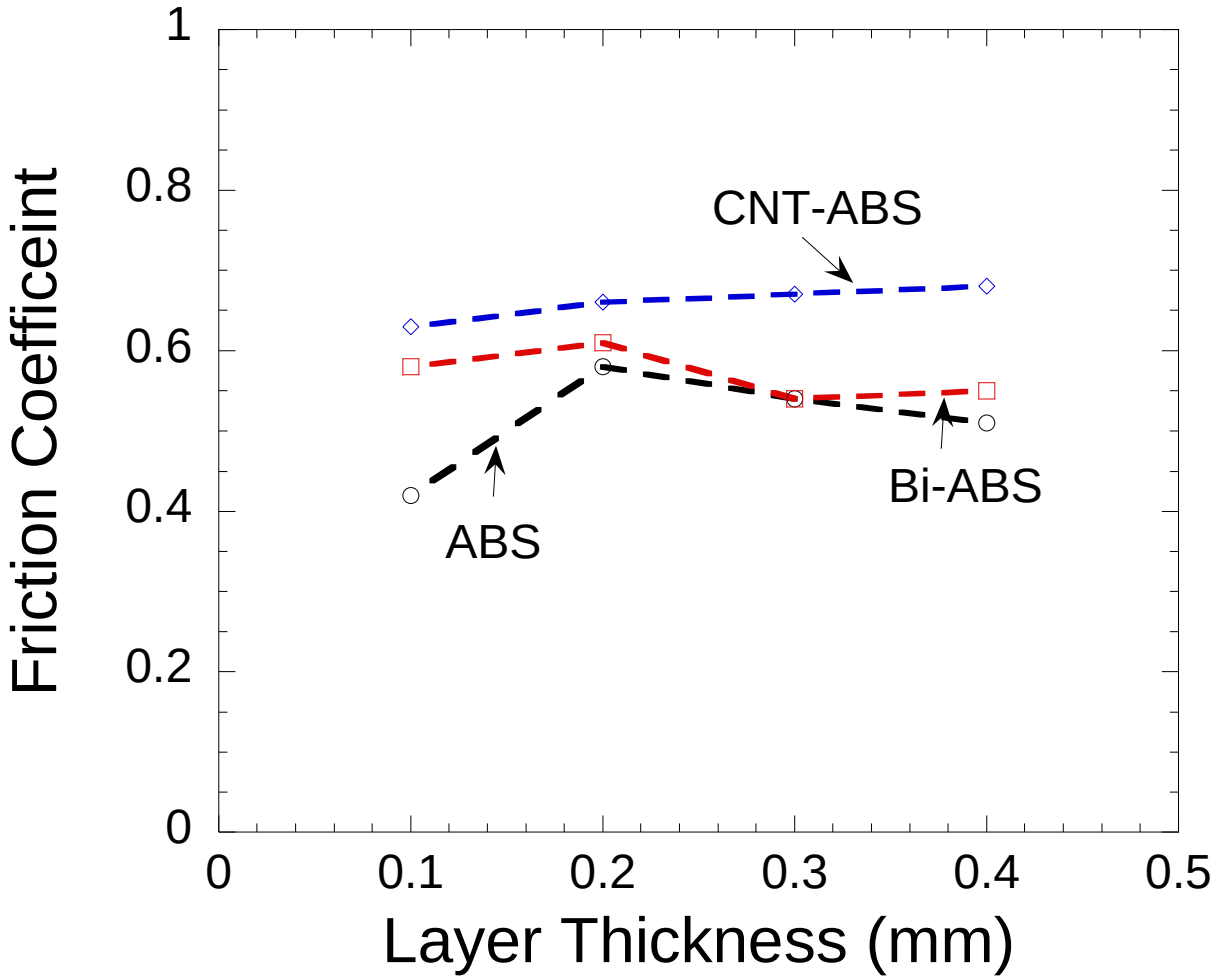
Variation of Friction Coefficient in ABS and ABS Composite Materials



Variation of Wear Rate vs Print Layer Height in ABS and ABS Composite Materials

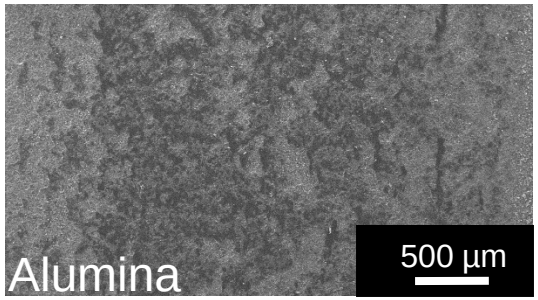


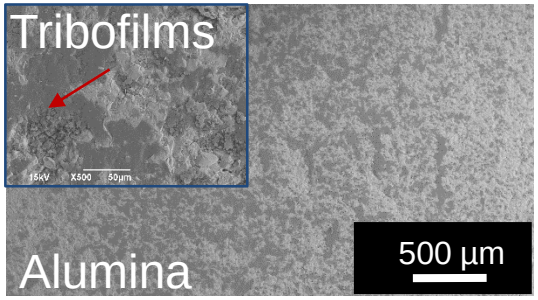
Variation of Friction Coefficient vs Print Layer Height in ABS and ABS Composites

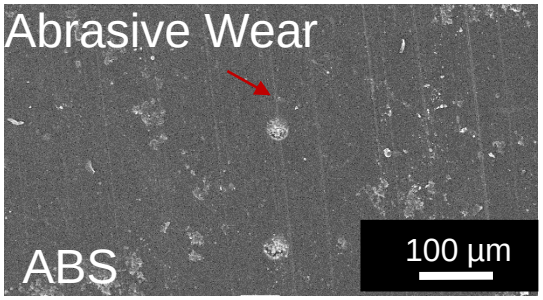


Wear Track Analysis

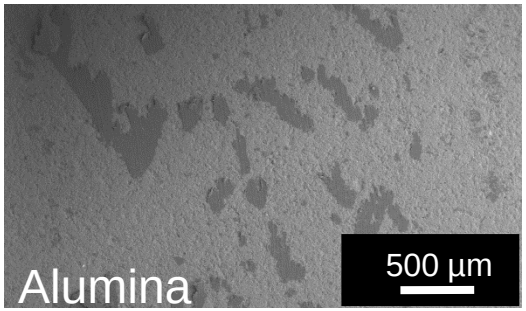
Alumina-ABS Tribocouple

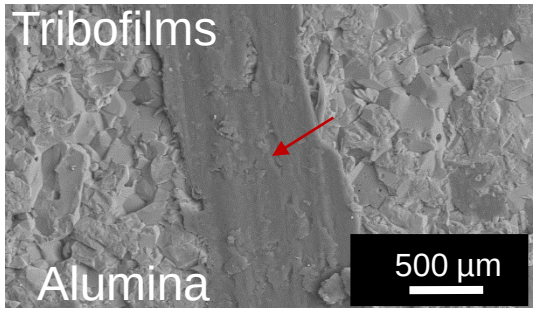


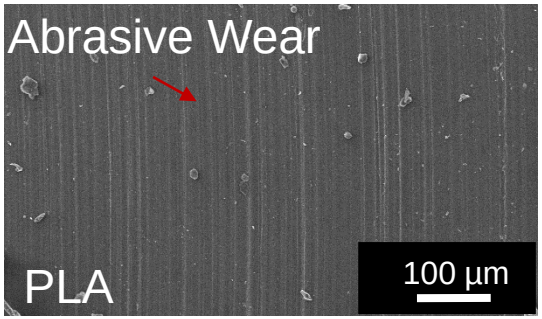




Alumina-PLA Tribocouple



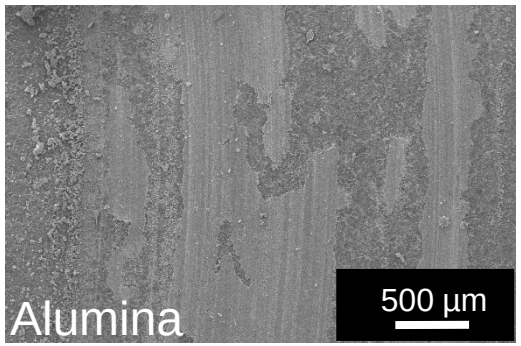


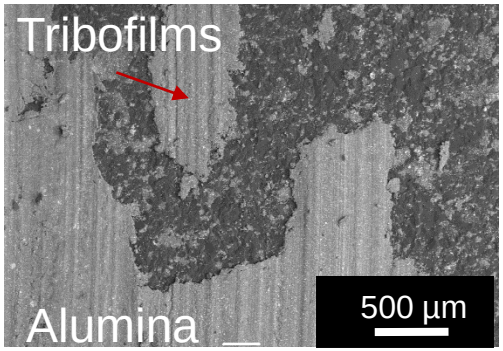


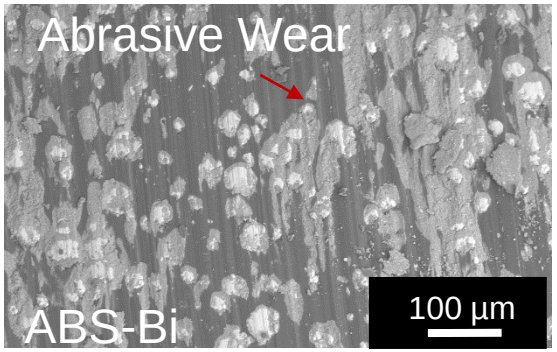
The Wear is Driven by the Formation of Tribofilms

Wear Track Analysis

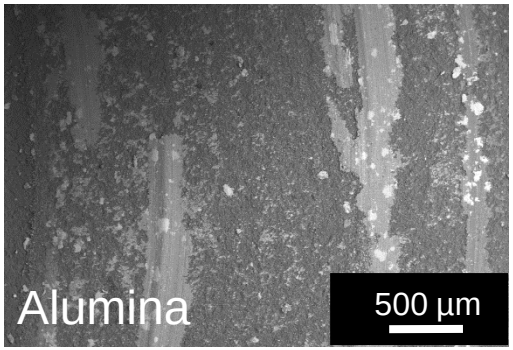
Alumina-ABS-Bi Tribocouple

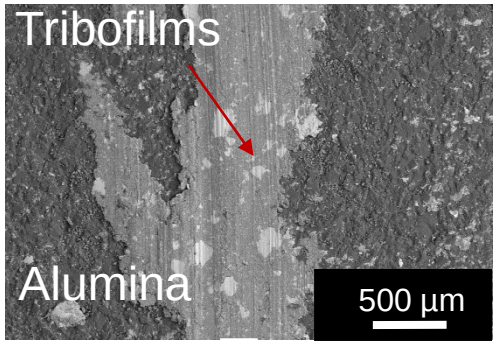


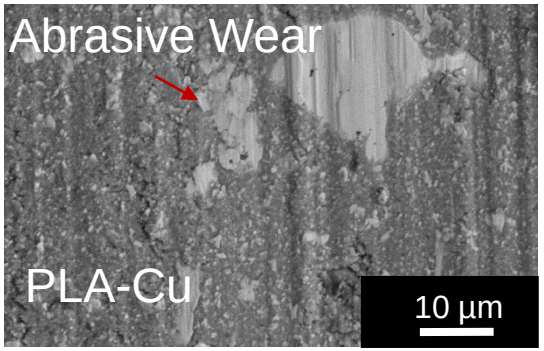




Alumina-PLA-Cu Tribocouple







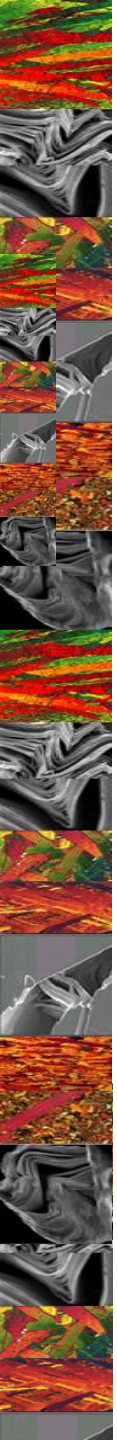
The Wear is Driven by the Formation of Tribofilms

Summary and Conclusions

- This study shows that the tribological behavior of PLA and ABS are dependent on layer thickness and particulate additives.
- PLA showed the lowest WR and μ as compared to the composites when the layer thickness was 0.1 mm
- As the layer thickness was gradually increased, the WR of the composites decreased as compared to PLA samples, and μ remained similar for all the samples.
- Similarly, ABS also showed the lowest WR and μ as compared to the composites when the layer thickness was 0.1 mm.
- As the layer thickness was gradually increased, the WR of the composites were similar to ABS samples, and μ of ABS and ABS-Bi became similar.
- Interestingly, CNT-ABS showed higher μ as compared to the ABS and Bi-ABS composites.
- Preliminary studies showed that the wear mechanisms are driven by the formation of tribofilms. More fundamental studies are needed to understand the intricate mechanism for the formation of tribofilms.

Acknowledgments

- NASA EPSCoR is acknowledged for funding.
- University of North Dakota Faculty Start Up
- University of North Dakota Seed Grant
- This work was also supported in part by the National Science Foundation through the University of Minnesota MRSEC under Award Number DMR-0819885.



CALL FOR PAPERS

Abstracts due December 15, 2015

9TH INTERNATIONAL CONFERENCE ON HIGH TEMPERATURE CERAMIC MATRIX COMPOSITES - HTCMC 9

GLOBAL FORUM ON ADVANCED MATERIALS AND TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT - GFMAT 2016

JUNE 26 – 30, 2016